

Open Research Online

The Open University's repository of research publications and other research outputs

Variations in Martian convective boundary layer depth: observations and modelling studies

Conference or Workshop Item

How to cite:

Lewis, S. R.; Hinson, D. P. and Spiga, A. (2011). Variations in Martian convective boundary layer depth: observations and modelling studies. In: Fourth International Workshop on the Mars Atmosphere: Modelling and Observations, 8-11 Feb 2011, Paris, France.

For guidance on citations see [FAQs](#).

© 2011 The Authors

Version: Version of Record

Link(s) to article on publisher's website:
<http://www-mars.lmd.jussieu.fr/paris2011/>

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data [policy](#) on reuse of materials please consult the policies page.

oro.open.ac.uk

VARIATIONS IN MARTIAN CONVECTIVE BOUNDARY LAYER DEPTH: OBSERVATIONS AND MODELLING STUDIES.

S. R. Lewis, *Department of Physics & Astronomy, The Open University, UK (s.r.lewis@open.ac.uk)*, **D. P. Hinson**, *SETI Institute, Mountain View, CA, USA (dhinson@seti.org)*, **A. Spiga**, *Laboratoire de Météorologie Dynamique, Université Pierre et Marie Curie, Paris, France (aymeric.spiga@upmc.fr)*.

Introduction:

Mars has a particularly active convective boundary layer during the day, which can extend to over 10 km altitude above the surface. Radio occultation observations [Hinson et al. 2008] have shown that the maximum depth of the martian convective boundary layer, usually reached during the late afternoon around 17:00LT, is strongly correlated with the surface elevation relative to a standard areoid, or, equivalently, strongly anti-correlated with surface pressure. This result has important implications for the global circulation and it is vital that atmospheric models are able to reproduce this behaviour. We show that a large-eddy simulation [Spiga et al. 2010; Spiga and Lewis 2010] does indeed exhibit a similar correlation and that a global model, with a turbulence closure planetary boundary layer parameterization and dry convection scheme [Forget et al. 1999], also shows evidence that the depth of convection is correlated with surface height. Results are shown from high- and medium-resolution simulations, including global models into which Thermal Emission Spectrometer thermal data from NASA Mars Global Surveyor has been assimilated [Lewis et al. 2007], although the observations do not themselves have sufficient vertical resolution to measure this feature directly. The implications for the global circulation when convective boundary layer depth varies with location are considered.

Radio Occultation Observations:

Hinson et al. [2008] used ESA Mars Express radio occultation observations with good coverage in local time of day and latitude to identify strong variations in the depth of the martian convective boundary layer at low latitudes. Figure 1 shows three occultations in the Utopia Planitia and the highlands surrounding Isidis Planitia in mid-spring of Mars Year 28 each made around 15:50LT. The depth of the boundary layer is strongly correlated with variations in surface elevation. This effect can be accentuated by the surface properties in Syrtis Major, where the low albedo results in a relatively high surface temperature, but the correlation with surface elevation is consistent at other sites on Mars.

Large-Eddy Simulations:

Figure 2 show the development of the convective boundary layer over the course of a day from two large-eddy simulations with similar surface properties, except for surface pressure [Spiga and Lewis 2010]. The boundary layer depth at 17:00LT is pre-

dicted in good agreement with values derived from Mars Express radio-occultation experiments [Hinson et al. 2008].

Global Modelling and Data Assimilation:

We next examine whether this behaviour is reproduced in a global atmospheric model, the UK spectral version of the European Mars GCM [Forget et al., 1999; Lewis and Read, 2003]. The global model has a 2.5 level Mellor-Yamada turbulence closure planetary boundary layer parameterization and enforces static stability with a dry convection scheme that ensures that the vertical gradient of potential temperature can never become negative; in contrast, super-adiabatic profiles are often observed on Mars close to the surface during the day [Schofield et al. 1997; Smith 2004; Smith et al. 2006].

Figure 3 shows a thermal cross-section though the model atmosphere from an experiment with very high horizontal resolution, a spectral truncation at total wavenumber 170 (T170), equivalent to a grid spacing of around 0.75° in latitude and longitude. At such high horizontal resolution, the model only has limited vertical resolution (25 levels to 100 km altitude, only the lower portion of the atmosphere is shown in Fig. 3). Figure 4 shows the corresponding potential temperature with the division between a lower atmosphere with essentially constant potential temperature in the vertical (fixed by the model convection scheme) and the main body of the atmosphere, which is statically stable.

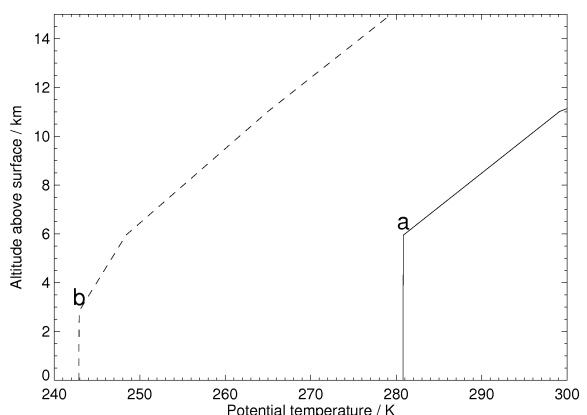


Figure 5: Potential temperature profiles taken from Fig. 4 at (a) 240°E , 10°S and (b) 240°E , 10°N , both at 16:00LT and plotted against altitude above the local surface in each case.

In order to make a clear comparison between profiles subject to the same heating and at the same local time, but at different surface elevations, Fig. 5

shows vertical potential temperature profiles taken from Fig. 4 at 10°S and 10°N. The first is on the flanks of Arsia Mons and has a surface elevation of about 12 km, the second has a surface elevation of about 0 km, both relative to the MOLA areoid [Smith et al. 2001]. Both are shown in altitude relative to their local surface for comparison. The convective boundary layer can be seen to be about twice as deep over the higher terrain. Although there are about 10 vertical levels below 10 km altitude, owing to the grid stretch used the grid spacing becomes coarser around the top of the boundary layer and it is difficult to locate the top of the boundary layer with any precision. Further experiments will be conducted with more modest horizontal resolution, but much greater vertical resolution.

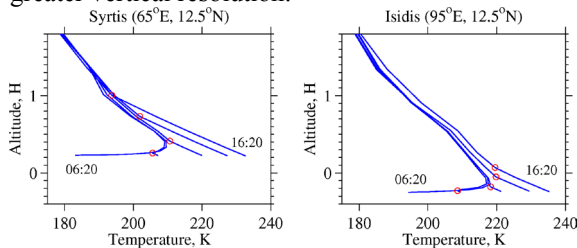


Figure 6: Temperature profiles plotted against altitude above the MOLA areoid at two-hourly intervals during the day. The red circles indicate the top of the convective boundary layer with the same criterion as in Fig. 4.

Figure 6 indicates the development of the boundary layer during the day from a model run at lower horizontal resolution (T31, or about a 3.75° grid) than that used in Figs. 3–5, but into which thermal and dust opacity data from the Thermal Emission Spectrometer thermal data on NASA Mars Global Surveyor has been assimilated [Lewis et al. 2007]. The sites have been chosen close to the radio occultations shown in Fig. 1 and may be compared, with the boundary layer in the model being a maximum in the profile at 16:20LT (closest to the observations at 15:50LT in Fig. 1) and a minimum at 06:20LT, with a strong night-time inversion.

Summary:

We have established that the convective boundary layer depth is correlated with surface elevation on Mars. This has important implications for the global circulation on Mars.

- It is important that any boundary layer parameterization used in a martian global model is able to reproduce this effect in order to model the circulation realistically and planetary boundary layer schemes should be validated against observations and detailed large-eddy simulations.
- Since the variation of boundary layer depth is fixed with respect to the surface it will act to enhance the, already large, martian topographic contrasts, affect stationary wave generation and modulate the non sun-synchronous thermal tides produced in the martian atmosphere as a result of

the interaction of the direct thermal tide with surface topographic and thermal variations.

- It is possible that variations in the boundary layer depth will induce differences in the large-scale martian circulation and Walker cell-like structures along latitude circles in equatorial regions.
- Wind speeds within the planetary boundary layer are strongly dependent on boundary layer depth [Spiga and Lewis 2010]. Regions where the convective boundary layer is deep will show enhanced wind speed, and so enhanced dust lifting, compared to regions where the boundary layer is less active.
- The convective boundary layer plays a vital role in surface-atmosphere interactions. Dust lifted from the surface is effectively mixed into the body of the atmosphere, where it may be transported by large-scale winds. Without convective mixing in the lower atmosphere, dust lifted by near-surface wind stress would remain at low altitudes and would rapidly fall out of the atmosphere [e.g. Newman et al. 2002]. Similarly, water vapour sublimated from surface sources and other trace gas, such as methane, will be mixed into the atmosphere. These processes will be much more efficient above regions of high surface elevation as a result of the variation in boundary layer depth.
- Accurate prediction of the turbulent winds in the convective boundary layer may be important to the safe entry, descent and landing of future spacecraft missions, such as NASA Mars Science Laboratory and ESA/NASA ExoMars. It is harder to land in regions of lower surface pressure since there is less atmospheric mass available on the descent trajectory to decelerate a spacecraft. A more active convective boundary layer above regions of high elevation could make landing in such regions even more hazardous.

References:

- Forget, F. et al. [1999] *JGR*, **104**, 24,155–24,176.
Hinson, D. P. et al. [2008] *Icarus*, **198**, 57–66.
Lewis, S. R. et al. [2007] *Icarus*, **192** (2), 327–347.
Lewis, S. R. and Read, P. L. [2003] *JGR*, **108** (E4), 5034.
Newman C. E. et al. [2002] *JGR*, **107** (E12), 5123.
Schofield J. T. et al. [1997] *Science*, **278**, 1752–1758.
Smith, D. E. et al. [2001] *JGR*, **106** (E10), 23,689–23,722.
Smith, M. D. [2004] *Icarus*, **167** (1), 148–165.
Smith, M. D. et al. [2006] *JGR*, **111** (E12), doi:10.1029/2006JE002770.
Spiga, A. and Forget, F. [2009] *JGR*, **114** (E13), doi:10.1029/2008JE003242.
Spiga, A. et al. [2010] *QJRM*, **136**, 414–428.
Spiga, A. and Lewis, S. R. [2010] *Mars*, doi:10.1555/mars001090.

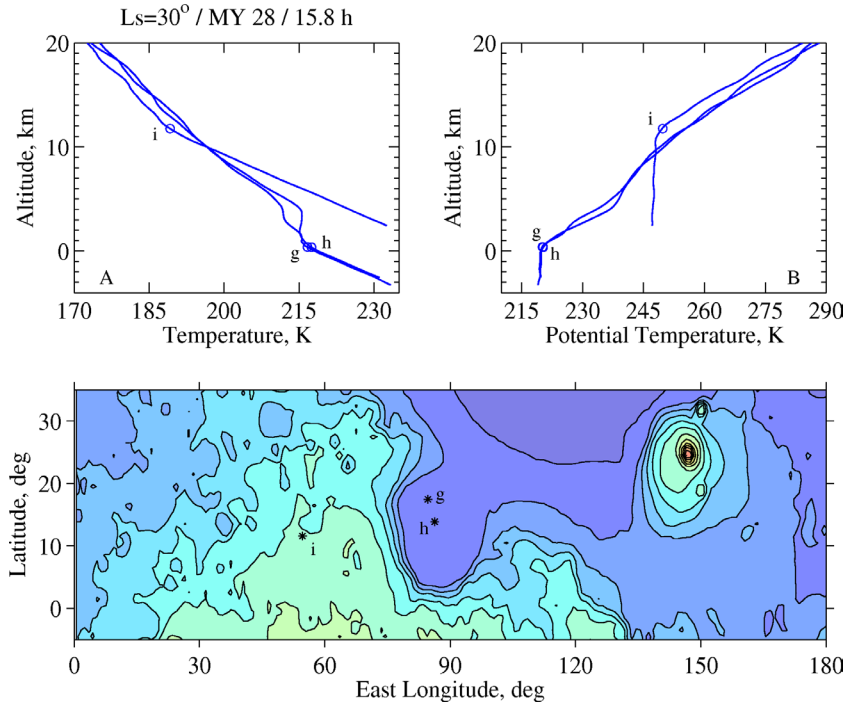


Figure 1: Three radio occultations (labeled g, h, i), showing temperature (upper left) and potential temperature (upper right) plotted against altitude relative to the MOLA reference datum [Smith et al. 2001] made in mid-spring ($L_s=30^\circ$) of Mars Year 28 around 15:50LT in Utopia Planitia and the highlands surrounding Isidis Planitia. The profiles are located on the lower panel, a map of surface elevation with contour interval of 1 km.

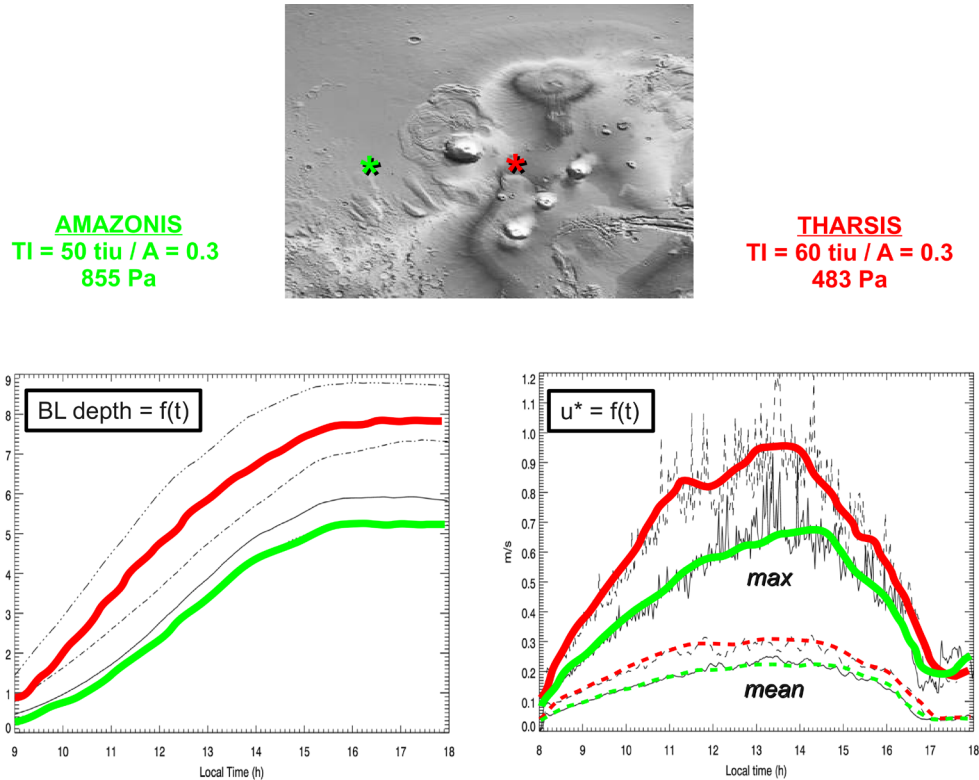


Figure 2: Large-Eddy Simulations carried out with the Spiga and Forget [2009] mesoscale model of (left) boundary layer depth and (right) friction velocity u^* in two locations with similar soil properties but distinct altitudes (Amazonis plains in green and Tharsis mountains in red). Amazonis and Tharsis large-eddy simulations are detailed in Spiga et al. [2010] with respective labels b and c. Values of u^* in full (dashed) lines correspond to maximum (mean) values in the simulation domain [from Spiga and Lewis 2010].

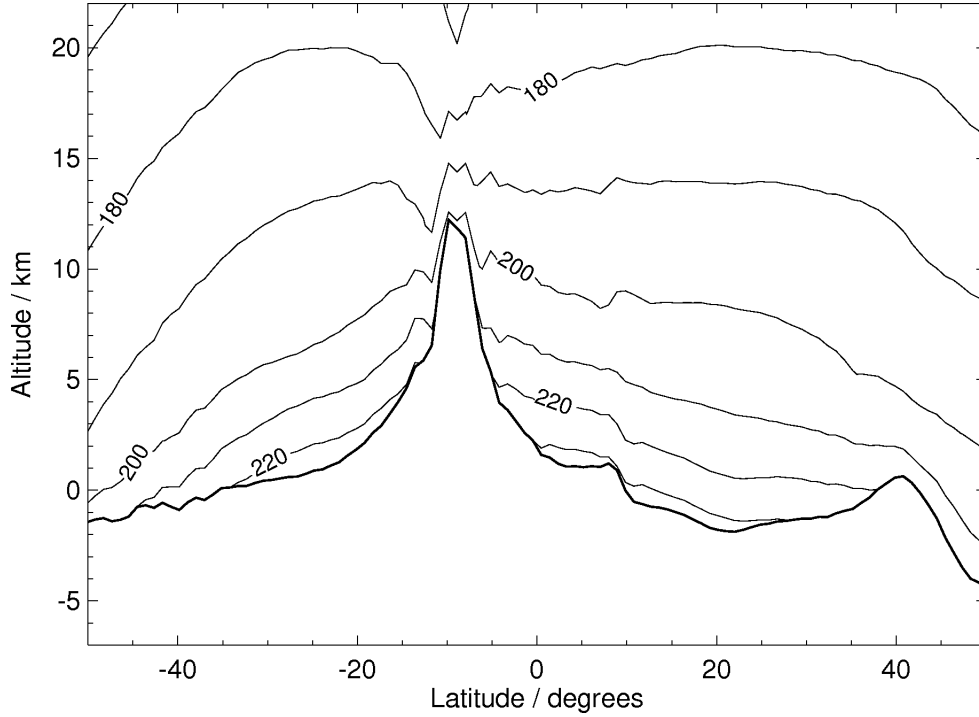


Figure 3: Latitude–altitude cross-section of absolute temperature at longitude 240°E and 16:00LT from the UK spectral version of the European Mars GCM [Forget et al., 1999; Lewis and Read, 2003] run at very high resolution (T170, i.e. a grid spacing of approximately 0.75° latitude and longitude). Altitude is expressed above the MOLA zero-datum reference, the cross-section includes the flank of Arsia Mons. The field is an average over 10 Martian days at $L_s = 0^\circ$ (northern spring equinox).

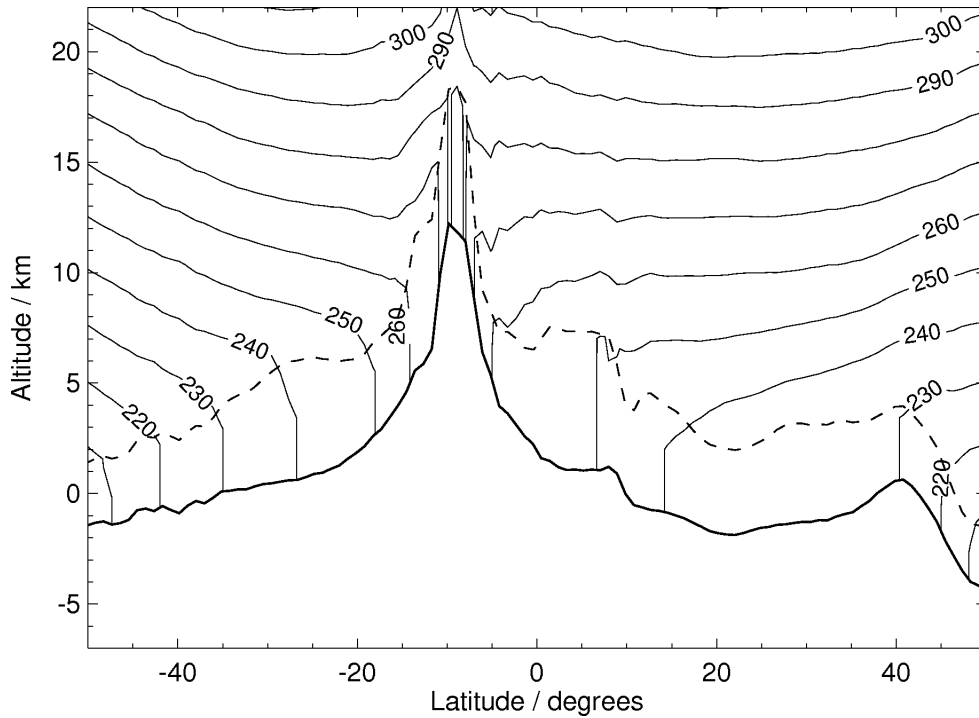


Figure 4: Latitude–altitude cross-section of potential temperature corresponding to Fig. 3. The dashed line shows the approximate altitude (the mid-point between two model levels) at which the vertical gradient of potential temperature exceeds 1.5 K/km, the definition used for the top of the convective boundary layer by Hinson et al. [2008] and in Fig. 1.